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EFFECT OF PROPERTIES OF SOLAR CORPUSCULAR FLOWS ON RATE OF ELECTRON FORMATION IN THE LOWER IONOSPHERE

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EFFECT OF PROPERTIES OF SOLAR CORPUSCULAR FLOWS ON RATE OF ELECTRON FORMATION IN THE LOWER IONOSPHERE

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ABSTRACT. Formulas are given for expressing altitude distribution of electron formation rate not only as a function of the distribution of ionized particles of the corpuscular flow by directions, but also as a function of their spectra, chemical composition, and the density of the atmosphere.

The problem of ionization of the lower ionosphere by intrusion of solar /1,918* corpuscular flows at high latitudes (the phenomenon of absorption at the polar cap) was solved in [1-3]. The following formula was obtained for the rate of electron formation [1]:

$$q(h) = 1{,}8\cdot 10^6 \rho(h) \sum_i \int_{E_m}^{E_\infty} \int_0^{\theta_c} n_i(E)\, 500 Z_i^2 \frac{\sin\theta}{\Psi(E,\theta)}\, d\theta\, dE, \qquad (1)$$

where $\rho(h)$ is the density of the atmosphere at altitude h in $g\cdot cm^{-3}$, θ is the angle between the normal and the direction of the penetrating particle, E is the kinetic energy in $MeV\text{-}nucleon^{-1}$, Z is the charge of the particle, n is the differential spectrum, Ψ is the law of reduction of energy with passage of the particles through the atmosphere, where

$$\Psi(E,\theta) = (E_m^2 - 10^3 \tilde{h} Z^2 \sec\theta)^{1/2},$$

In the above, E_m is determined by the geomagnetic, atmospheric or energetic reduction as follows:

$$E_m = \max[E_R = 10^3[\sqrt{(Z/A)^2 R^2 + 1} - 1];$$
$$E_A = (10^3 \tilde{h} Z^2 \sec\theta + 1)^{1/2};\ E_E],$$

Here R and A are the hardness and atomic weight of the particle, $\tilde{h}$ is the depth of the atmosphere at altitude h. Equation (1) summarizes the ionization of all forms of particles i in the composition of solar cosmic rays.

*Numbers in the margin indicate pagination in the foreign text.

Let us draw some inferences from the results in [1, 2]. We know that the particle distribution differs considerably in different directions at different moments of the penetration of solar corpuscular flows. At the beginning, the particles are distributed anisotropically in the upper hemisphere, then isotropically. The differential spectrum can therefore be expressed as follows:

$$n(E, \theta) = n(E) F(\theta) = n(E) C_n \cos^n \theta, \tag{2}$$

Where C_n and n are constants. If we insert distribution (2) in expression (1), we will have:

$$q(h) = 1{,}8 \cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} \int_0^{\theta_c} n_i(E)\, 500 Z_i^2 \frac{C_n \cos^n \theta \sin \theta}{\Psi(E, \theta)}\, d\theta\, dE.$$

Following integration, we will obtain the general expression /1,919

$$q(h) = 1{,}8 \cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} n_i(E) Z_i^2 \frac{500 C_n}{E} \times$$
$$\times \left[\sqrt{1 - \left(\frac{E_{Ai}}{E}\right)^2} \sum_{l=1}^{n+1} \frac{1}{l} \prod_{k=l}^{n} \frac{(2k+1)}{(2k+2)} \left(\frac{E_{Ai}}{E}\right)^2 + \right. \tag{3}$$
$$\left. + \ln \frac{1 + (1 + E_{Ai}^2/E^2)^{1/2}}{1 - (1 - E_{Ai}^2/E^2)^{1/2}} \prod_{k=0}^{n} \frac{(2k+1)}{(2k+2)} \left(\frac{E_{Ai}}{E}\right)^2 \right] dE.$$

In order to study the effect of the function of distribution of the particles of the corpuscular flow on the rate of electron formation in the ionosphere, we must determine the constant C_n from the normalization condition:

$$\int_0^{\pi/2} n(E) C_n \cos^n \theta \sin \theta\, d\theta =$$
$$= \int_0^{\pi/2} n(E) \sin \theta\, d\theta = n(E),$$

from which we obtain

$$C_n = n + 1.$$

Let us examine the concrete solutions corresponding to the development of this effect with time:

a) During the first few hours of penetration of a solar corpuscular flow, the particles are distributed completely anisotropically as to direction, i.e., $n \to \infty$. In this case we can use the result obtained in (1):

$$q(h) = 1{,}8 \cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} n_i(E) Z_i^2 \, 190 \, \frac{\ln \Psi(E, \theta) + 1{,}4}{\Psi(E, \theta)} dE. \tag{4}$$

In particular, $\theta = 0$ corresponds to vertical penetration.

b) A certain degree of isotropization then begins, i.e., n grows smaller. From the general formula (3) we can obtain solutions for different distribution functions. For example, in the case $n = 2$ we will have

$$q(h) = 1{,}8 \cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} n_i(E) Z_i^2 \cdot \frac{1500}{E} \times$$
$$\times \left\{ \sqrt{1 - \left(\frac{E_{Ai}}{E}\right)^2} \left[\frac{5}{8} \left(\frac{E_{Ai}}{E}\right)^4 + \frac{5}{12} \left(\frac{E_{Ai}}{E}\right)^2 + \frac{1}{3} \right] + \right. \tag{5}$$
$$\left. + \frac{5}{16} \left(\frac{E_{Ai}}{E}\right)^6 \ln \frac{1 + (1 - E_{Ai}^2/E^2)^{1/2}}{1 - (1 - E_{Ai}/E)^{1/2}} \right\} dE.$$

c) During the next several days the spatial distribution of the particles becomes practically isotropic ($n = 0$). From the general expression (3) we will have for this case: /1,920

$$q(h) = 1{,}8 \cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} n_i(E) Z_i^2 \frac{500}{E} \times$$
$$\times \left[\sqrt{1 - \left(\frac{E_{Ai}}{E}\right)^2} + \frac{1}{2} \left(\frac{E_{Ai}}{E}\right)^2 \ln \frac{1 + (1 - E_{Ai}^2/E^2)^{1/2}}{1 - (1 - E_{Ai}^2/E^2)^{1/2}} \right] dE. \tag{6}$$

If we take into account the effect of ionization at the upper limit, $\theta_c = \pi/2$, or more generally:

$$\theta_c = \frac{\pi}{2} + \arcsin\left[(2ah + h^2)^{1/2}/(a + h)\right],$$

where a is the radius of the Earth, in the case of a spherical atmosphere we can write:

$$q(h) = 1{,}8\cdot 10^5 \rho(h) \sum_i \int_{E_m}^{E_\infty} n_i(E) Z_i^2 \frac{500}{E} \times$$
$$\times \left[\sqrt{1-\left(\frac{E_{Ai}}{E}\right)^2} + \frac{1}{2}\left(\frac{E_{Ai}}{E}\right)^2 \ln \frac{1+(1-E_{Ai}^2/E^2)^{1/2}}{1-(1-E_{Ai}^2/E^2)^{1/2}} - \right.$$
$$\left. - \frac{1}{Ch(\theta_c h)} \sqrt{1-\frac{E_{Ai}^2(\theta_c)}{E^2}} - \frac{1}{2}\left(\frac{E_{Ai}}{E}\right)^2 \ln \frac{1+[1-E_{Ai}^2(\theta_c)/E^2]^{1/2}}{1-[1-E_{Ai}^2(\theta_c)/E^2]^{1/2}} \right] \times$$
$$\times dE.$$

All of these formulas express the altitude distribution of the electron formation rate not only as a function of the distribution of ionized particles of the corpuscular flow by directions, but also as a function of their spectra, chemical composition, and the density of the atmosphere.

For a quantitative evaluation of the results, we have performed a numerical integration using the spectrum

$$n(E) = 4\cdot 10^9 E^{-5} \text{ proton}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1}\cdot\text{ster}^{-1}\cdot\text{MeV}^{-1}$$

and the cut-off threshold in the low-energy region is 20 MeV. Figure 1 shows the results of integration of (4) - (6), i.e., of the cases of completely anisotropic vertical flow, and flows with anisotropic (n = 2) and isotropic distributions of penetrating particles.

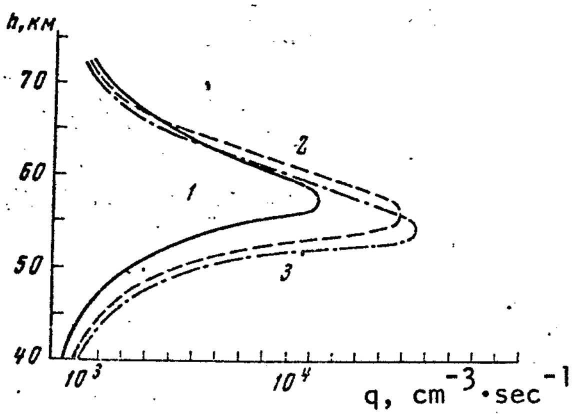

Figure 1. Distribution of Rate of Electron Formation with Height for Cases of (1) Completely Anisotropic Vertical Flow, (2) Partly Anisotropic (n = 2) Flow, and (3) Completely Isotropic Particle Flow.

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